~~CONFIDENTIAL~~

Copy 386
RM L51E10a

Paul G. Fournier

NACA

RESEARCH MEMORANDUM

AERODYNAMIC CHARACTERISTICS OF WINGS DESIGNED FOR STRUCTURAL IMPROVEMENT

By Joseph Weil and Edward C. Polhamus

Langley Aeronautical Laboratory
Langley Field, Va.

CLASSIFICATION CHANGED TO UNCLASSIFIED
AUTHORITY: NACA RESEARCH ABSTRACT NO. 109
EFFECTIVE DATE: NOVEMBER 14, 1956 WHL

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

May 28, 1951

~~CONFIDENTIAL~~

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

AERODYNAMIC CHARACTERISTICS OF WINGS DESIGNED FOR STRUCTURAL IMPROVEMENT

By Joseph Weil and Edward C. Polhamus

I.- WING THICKNESS

From the structural design standpoint it is obviously desirable to use thick wing sections because, for a given design skin stress, it offers a means of obtaining the greatest structural rigidity at the lowest cost in structural weight. In addition there is the utility of having greater space available within the wing for internal storage. A brief review of the effect of wing thickness and thickness distribution on the high-speed performance and stability characteristics of a representative configuration is presented.

Details of the models used to illustrate thickness effects are shown in figure 1. The wing had an aspect ratio of 6 with quarter-chord sweepback of 45° and taper ratio 0.6. Wings having constant streamwise thickness ratios of 6, 9, and 12 percent and a wing tapering from 9 percent at the root to 3 percent at the tip were investigated on the transonic bump at Reynolds numbers of somewhat less than a million. The same wing plan form was also investigated by use of the rocket technique at Reynolds numbers of from 4 to 7 million. Data were obtained by the rocket technique for a constant wing thickness ratio of 9 percent and also with the wing tapering from 9 percent at 40 percent of the semispan to 16 percent at the theoretical root. The wing thickness ratio at the fuselage juncture was about 14.5 percent. A fineness-ratio-10 fuselage was utilized for this study.

Variation of lift slope, lateral center of pressure, and pitching-moment slope with Mach number at low lift coefficients for the thickness series investigated on the transonic bump is shown in figure 2. All data have been corrected to the same wing stiffness level and, therefore, differences shown in the data presented in figure 2 should be primarily attributable to aerodynamic rather than to aeroelastic effects. For the thicker wings a large loss in lift slope is present at transonic speeds. This loss in lift slope occurred at the tip sections as verified by the inboard movements of the lateral center of pressure. The loss in tip load also produced large unstable aerodynamic-center movements.

These aerodynamic-center movements occur at low lift coefficients and could produce undesirable stability and trim characteristics in this speed range. The fact that these phenomena are primarily a function of the thickness ratio over the outboard-wing sections is brought out by the smooth variation of the various parameters for the wing of constant 6 percent thickness and the wing tapered from 9 percent at the root to 3 percent at the tip. It would appear from these and other data that outboard-wing thickness ratios not much in excess of 6 percent are desirable for the attainment of satisfactory stability and trim characteristics at transonic speeds for swept wings of moderate and high aspect ratio.

The variation of minimum drag coefficient with Mach number as obtained from bump and rocket tests is presented in figure 3. It should be mentioned that there were considerable effects of thickness ratio indicated in the minimum drag characteristics of the bump data at subcritical Mach numbers. These effects, however, were believed to be distorted by the low Reynolds numbers of the investigations and, therefore, for purposes of analysis drag results were adjusted to the same value at a Mach number of 0.8. As expected, there is a large increase in minimum drag for the thicker wings as well as an earlier drag rise. The most interesting point to note is that the wing tapered in thickness from 9 percent at the root to 3 percent at the tip shows less drag than the wing of constant 6 percent thickness.

The rocket test data have been analyzed by subtracting the fuselage-alone drag from that of the wing-fuselage combination; thus, the drag shown represents the drag of the wing plus mutual interference. The largest increase in drag attributable to the thickened inboard section is present between Mach numbers of 0.95 and 1.05. It is interesting to note that at the highest Mach numbers the drag coefficient of the gloved wing is considerably less than would be estimated from the experimental 9-percent-thick-wing drag. This effect might, however, be caused in part by wing-fuselage-interference effects.

In order to analyze these data in terms of structural parameters, figure 4 was prepared. In this figure the minimum drag coefficient at a Mach number of 1.15 obtained from the transonic-bump investigations are plotted against wing-thickness ratio. In addition, the structural weight required for a skin stress of 30,000 pounds per square inch was estimated for an assumed design wing loading of 300 pounds per square foot and is plotted in terms of the structural weight required to meet the same design condition for the tapered-in-thickness wing. The ratio of streamwise aeroelastic twist at the wing tip to the twist estimated for the tapered-in-thickness wing was computed by use of simple beam theory with a ratio of GJ/EI of 0.83.

It is seen that the minimum drag coefficient of the tapered configuration is somewhat less than that obtained for the 6-percent-thick wing. However, the structural wing weight is about 50 percent greater and the aeroelastic twist is about 20 percent greater for the 6-percent-thick wing than for the wing with thickness ratio of 9 to 3. Although the tapered-in-thickness wing is structurally equivalent to a constant-thickness wing of about 7.5, it is somewhat better in performance than a 6-percent-thick wing.

II.- COMPOSITE PLAN-FORM WINGS

Four or five years ago both in this country and elsewhere composite plan forms composed of sweptback and sweptforward sections were proposed in order to alleviate the low-speed stability problems associated with sweptback wings. Figure 5 illustrates the improvement in the low-speed pitching-moment characteristics produced by such a plan form. In this figure the pitching-moment coefficient is plotted against lift coefficient for aspect-ratio-6 wings with sweep of 45°, taper ratio 0.6, and NACA 65A009 airfoil section parallel to the plane of symmetry. It is seen that, although an unstable pitching-moment variation is evident for the sweptback wing above lift coefficients of 0.5, the W plan-form wing with midsemispan break shows a satisfactory pitching-moment variation to stall.

Although stability improvements were indicated for M and W plan-form wings it was thought that the presence of additional junctures would cancel a good deal of the favorable sweep effect on drag at high speed and, therefore, nothing was done to develop these wing plan forms. Recently, however, members of the Langley Laboratory have pointed out the possible aeroelastic advantages of M and W wings as compared with conventional sweptback wings. One of these advantages is illustrated in figure 6.

Figure 6 presents the experimental variation of streamwise twist under air load across the semispan of wings of aspect ratio 6, sweep of 45°, taper ratio 0.6, and NACA 65A009 airfoil sections parallel to the plane of symmetry for loads producing unit tip deflection of the sweptback wings. It is evident that, although the shape of the deflection curves of the sweptback wings are little affected by the ratio of torsional to bending stiffness (GJ/EI), the M and W plan-form wings are very sensitive to this parameter. For example, with a value of GJ/EI of 1.60 the twist characteristics of the W plan form with midsemispan break would appear very desirable; whereas with a value of GJ/EI of 0.83 there is an undesirable divergent tendency over the outer wing sections. Large changes in the deflection characteristics could similarly be expected by changing the spanwise location of the plan-form break or by tapering the wing in thickness or plan form, and so forth. It therefore appears quite possible to design a composite plan form with essentially no streamwise twist for most flight conditions.

A comparison of the aerodynamic characteristics of M, W, and sweptback wings at subsonic and transonic speeds (reference 1) is presented in figure 7. All three wings were of aspect ratio 6 with 45° sweep, taper ratio 0.6, and NACA 65A009 airfoil sections parallel to the plane of symmetry. The M and W plan forms had midsemispan breaks. From the variations of lift slope, lateral center of pressure, and pitching-moment slope with Mach number it is evident that the M and W plan forms show more gradual variations of the various parameters with Mach number. The inboard shift in center of load and the unstable trend in pitching-moment slope which is indicated for the 9-percent-thick sweptback wing at transonic speeds is not present in the data of the 9-percent-thick M and W wings.

A comparison of the variation of minimum drag coefficient with Mach number for sweptback and M and W plan-form wings of aspect ratio 6 which were obtained from wind-tunnel tests (reference 1) and by the rocket technique are presented in figure 8. The wind-tunnel results indicate a slightly earlier drag rise for the M and W wings although a comparison with the drag estimated for an unswept wing with the same streamwise thickness ratio indicates that a large percent of the sweep effect is being realized. An earlier drag rise is also shown for the M plan form from the rocket investigation, although at Mach numbers above 1.1 the M wing actually has slightly less drag than the sweptback wing.

Figure 9 shows a comparison of the drag due to lift for the sweptback and M and W plan-form wings at Mach numbers of 0.90 and 1.08. It will be noted that at both Mach numbers the drag due to lift of the W wing is considerably greater than that for the sweptback wing whereas that for the M wing differs only slightly from that for the sweptback wing. The increase in drag due to lift indicated for the W plan form is probably caused by boundary-layer drainage into the midspan juncture. There are indications that the losses shown might be considerably reduced at higher Reynolds numbers and such information will be obtained by utilizing these same plan forms.

The variation of pitching-moment and drag coefficients with lift coefficient at a Mach number of 1.38 for sweptback and M and W plan-form wings is presented in figure 10. The wings were of aspect ratio 4 with sweep of 60° and taper ratio 1.0 and the streamwise airfoil sections were NACA 65A006. It is evident that the undesirable pitching moment characteristics at the higher lift coefficients shown for the sweptback wing are improved considerably when M and W plan forms are utilized. This improvement is similar in nature to that previously indicated at low speeds. The minimum drag for all three plan forms is essentially the same. The drag due to lift is somewhat better for the sweptback wing at the lower lift coefficients; whereas at the higher lift coefficients the drag is lower for the composite plan-form wings, particularly the M wing.

The results of another attempt to improve the structural characteristics of a sweptback wing are shown in figure 11. A basic aspect-ratio-6 wing of 45° sweepback was modified in plan form by adding a triangular area inboard of the 0.40 semispan station. This modification resulted in an increase in the exposed area of about 25 percent and a trailing-edge sweepforward slightly greater in magnitude than the original trailing-edge sweepback. The original 65A009 airfoils were broken at maximum thickness and the rear elements were sheared back to the new trailing edge - the segments of the original airfoil being connected by a flat-sided section the extent of which is shown by the cross-hatching. The drag coefficients of the wing-fuselage combination minus fuselage alone based on the exposed area of the original sweptback wing are presented. Drag rise for the modified wing occurred at a slightly higher Mach number. At supersonic speeds the drag of the larger modified wing was considerably less than that of the swept wing. Thus, reduced pressure drag, probably as a result of wing-fuselage interference, more than compensates the increased skin-friction drag. Aerodynamic data for lifting conditions, however, are needed in order to make a more complete evaluation of this configuration.

CONCLUSIONS

In conclusion it has been shown that thick wings of uniform-thickness ratio although desirable structurally are bad from the performance and stability standpoint. By tapering the thickness ratio judiciously, however, it may be possible to obtain performance and stability characteristics at transonic speeds which are superior to those of a structurally equivalent wing of constant-thickness ratio.

The use of M and W wings would appear to offer an attractive means of improving the stability characteristics and of reducing wing aeroelastic effects at all speeds. Although the minimum drag is somewhat higher at Mach numbers near force break there is little difference in minimum drag above relatively low supersonic speeds. The drag due to lift of W wings would appear to be somewhat greater than of comparable sweptback wings at transonic speeds but higher Reynolds number data are needed to substantiate this effect.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va.

REFERENCE

1. Campbell, George S., and Morrison, William D., Jr.: A Small-Scale Investigation of "M" and "W" Wings at Transonic Speeds. NACA RM L50H25a, 1950.

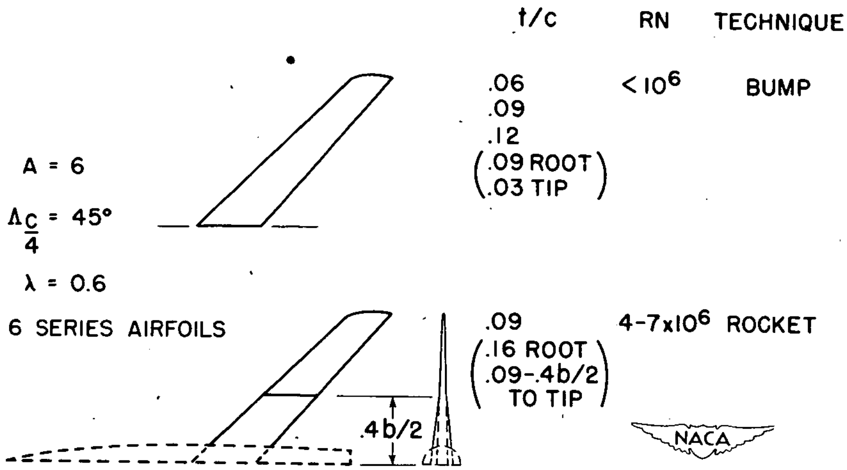

Figure 1.- Summary of configurations used for thickness investigation.

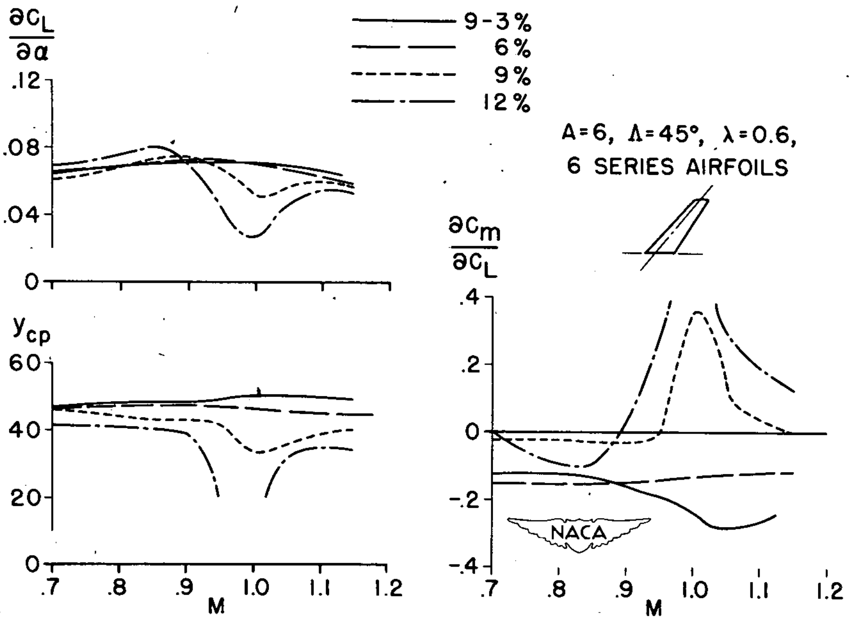

Figure 2.- Effect of wing thickness and thickness distribution on the aerodynamic characteristics at transonic speeds - transonic-bump technique.

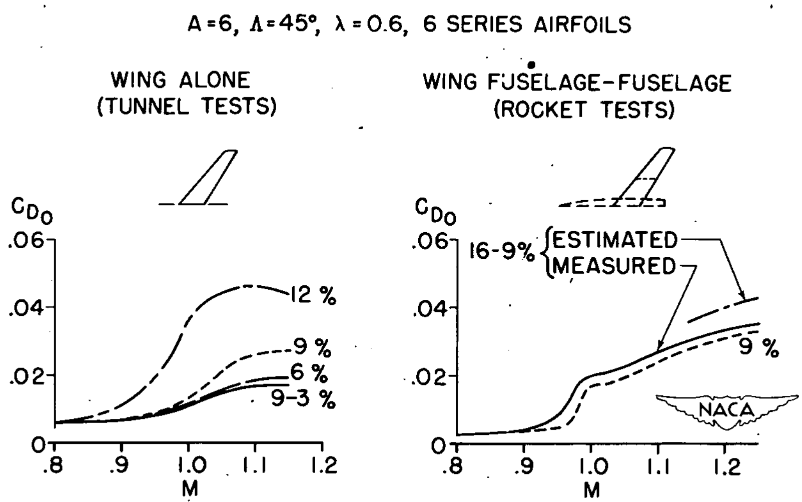

Figure 3.- Effect of wing thickness and thickness distribution on the variation of minimum drag with Mach number.

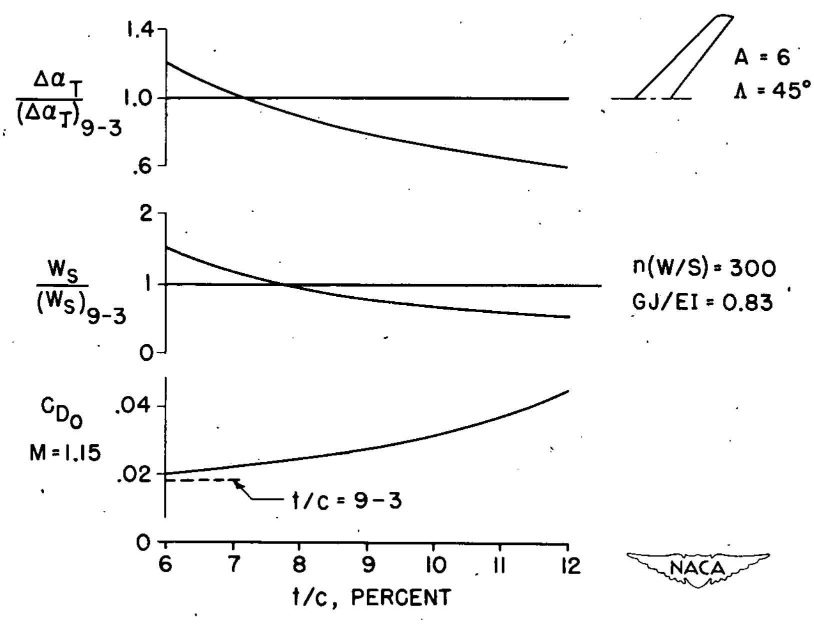

Figure 4.- Analysis of wing-thickness effects on minimum drag, structural wing weight, and aeroelastic twist.

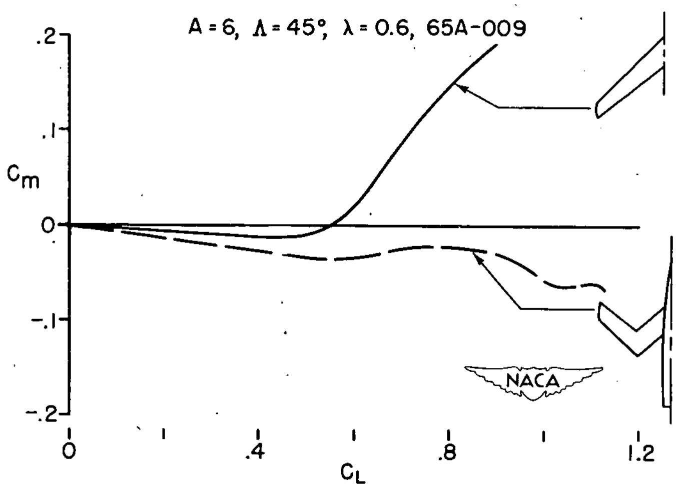

Figure 5.- Effect of plan form on the low-speed pitching-moment characteristics.

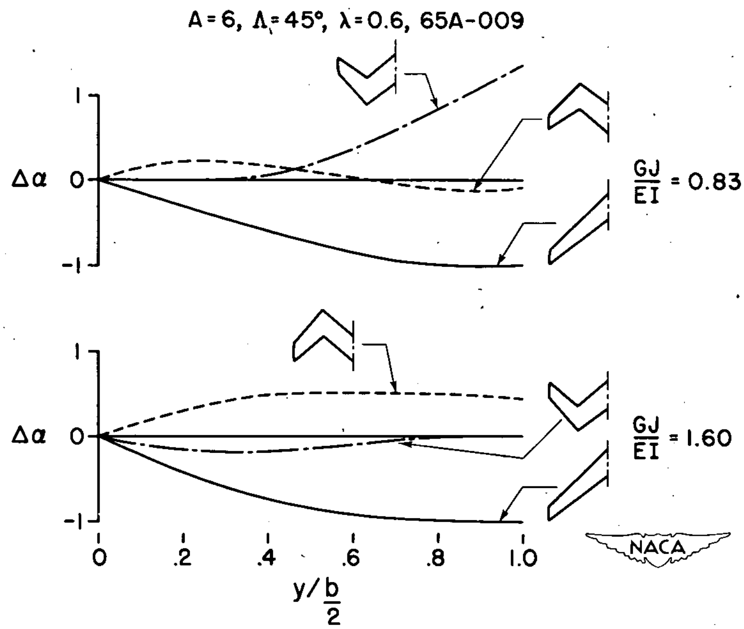

Figure 6.- Experimental streamwise twist under load for M, W, and sweptback wings.

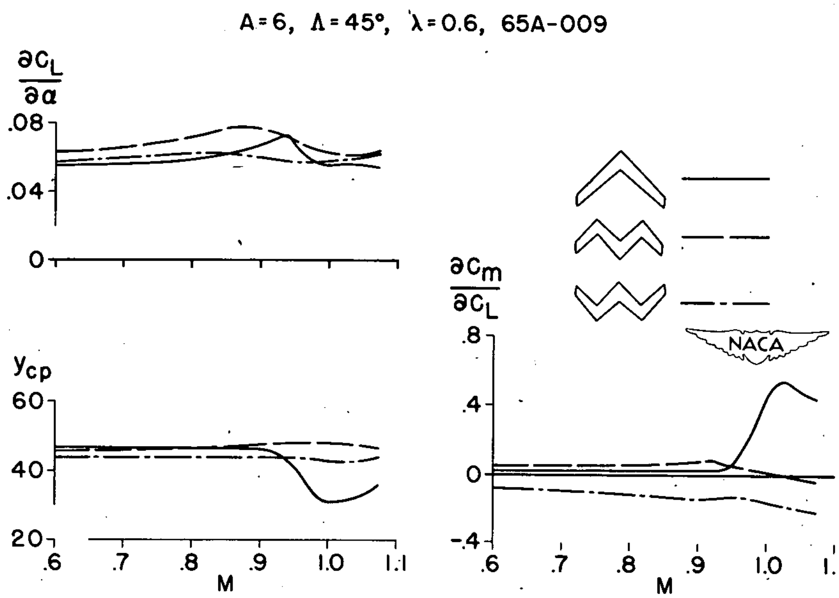

Figure 7.- Transonic aerodynamic characteristics of M, W, and sweptback wings.

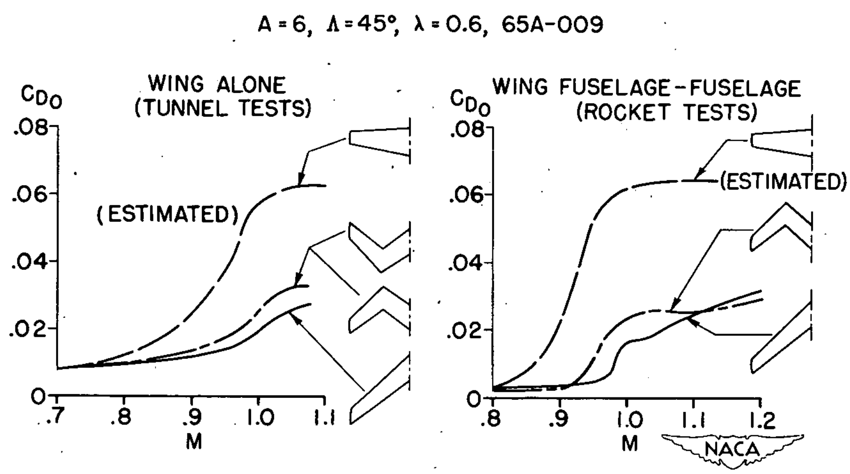

Figure 8.- Drag at zero lift for M, W, and sweptback wings at transonic speeds.

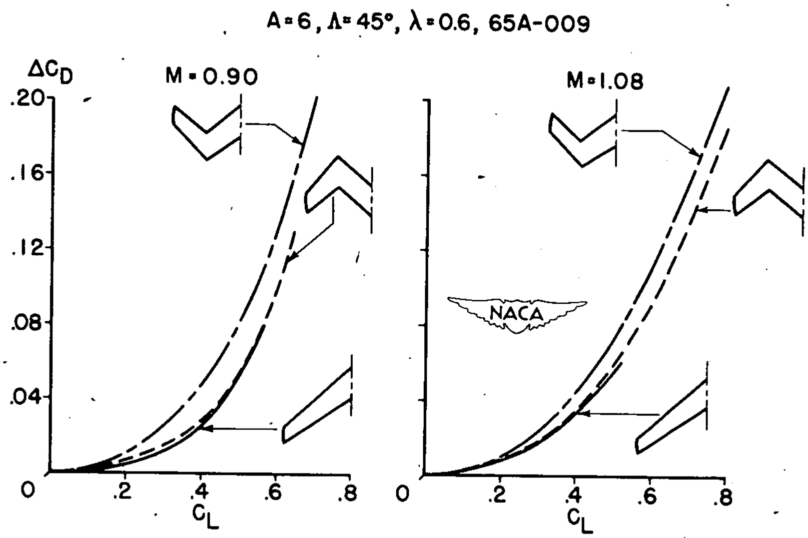

Figure 9.- Drag due to lift for M, W, and sweptback wings at transonic speeds.

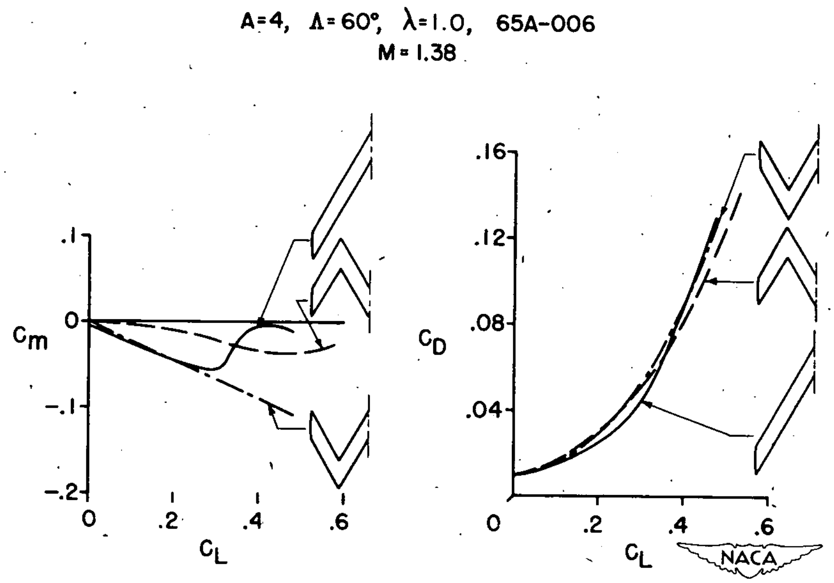

Figure 10.- Pitching-moment and drag characteristics of M, W, and sweptback wings at M = 1.38. R = 0.4×10^6.

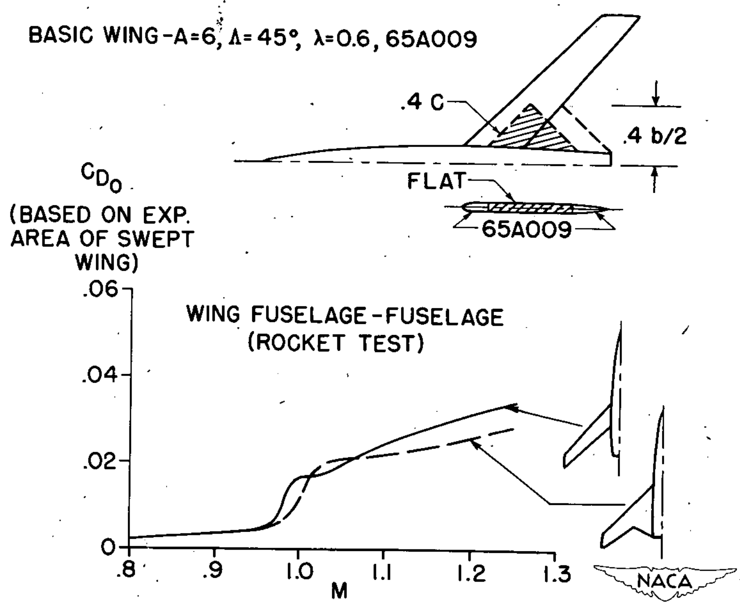

Figure 11.- Effect of plan-form modification on the variation of minimum drag with Mach number.